EATON | Cutler-Hammer

The Power Sheet

Consulting Engineer Edition

DRIVE BASICS

INTRODUCTION

Over the past 15 years, variable frequency drives are prevalent in commercial buildings heating, ventilating, and air conditioning applications (HVAC). The cost for drives has dropped making drives suitable for more applications. Further, the electronics used in drives now are very reliable. For these reasons, low level, less complex applications take advantage of the benefits offered by drives.

The purpose of the newsletter is to provide specifying engineers with basic information about drives. Highly complex applications require high-level application support, which is available from Cutler-Hammer right here in Milwaukee, Wisconsin.

WHY USE A DRIVE?

Why use a drive? Anytime time changing the work performed by a motor is a benefit. These include the following:

- Optimization or change a process
- Energy Savings
- Controlled Acceleration
- Limit Torque to Prevent Damage to Machinery

The purpose of a drive is to control the work performed by a motor. Again - the purpose of a drive is to control motor work; not to change the motor frequency! Work is defined as applied force to move an object. Horsepower is the rate that work is performed. Torque is a measure is of rotational force.

How are horsepower and torque related? See the following conversion formula:

$$\text{Horsepower} = \frac{\text{Torque x Speed}}{5250}$$

As the formula shows, controlling motor speed allow us to control the work performed by the motor. Now look at the below motor formula which relates frequency and speed:

$$\text{Speed} = \frac{\text{120 x Frequency}}{\text{Number of Motor Poles}}$$

Therefore, controlling the frequency controls the speed, which controls the work performed by the motor.

VARIABLE and CONSTANT TORQUE LOADS

There are type types of loads driven by a motor – Variable torque and Constant torque. Variable torque loads are the most common and, as stated in the name, the amount of torque needed to move the load varies with speed. Figure 1 shows how the torque required by a variable load changes with the speed of the motor. One important note,

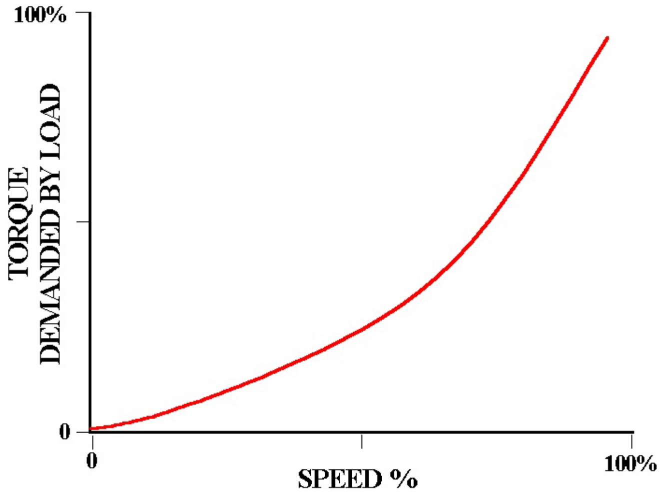

FIGURE 1 - Variable Torque Load

EATON CUTLER-HAMMER OFFERS a COMPLETE LINE OF VARIABLE FREQUENCY DRIVES

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the torque curve is not linear; rather the curve is more exponential in shape. This important when the types of control are discussed. Examples of variable torque loads are centrifugal pumps and centrifugal fans.

Constant torque loads are those loads where the torque requirements are the same; regardless of the speed the load is moving. Figure 2 shows the relationship of a constant torque load and speed. Examples of constant torque loads include crane hoists and positive displacement (piston type) pumps.

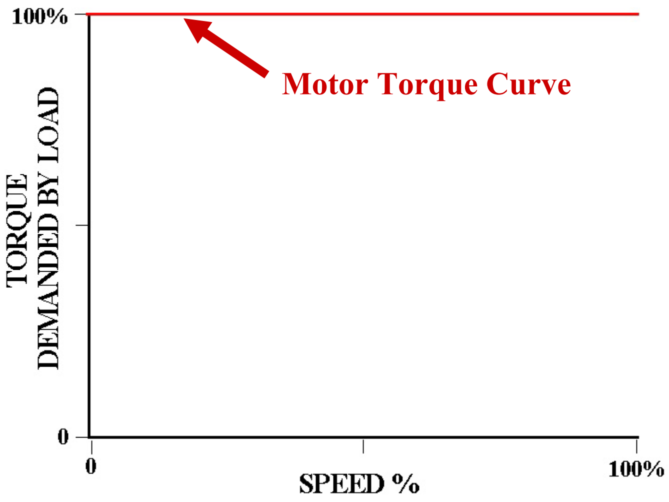

FIGURE 2 - Constant Torque Load

Drives are sized for motors based on the torque requirements of the load. Therefore, the drive sizing is influenced on whether the load is constant torque or variable torque. In general for motors of the same horsepower, constant torque loads require a larger drive than variable torque loads.

HOW DOES A DRIVE WORK?

All drives use three basic components: converter section, filter section, and an inverter section. A schematic diagram of a VFD hardware is shown in Figure 4.

The three hardware sections perform the following functions: – Converter from AC wave to DC, Filtering section to clean the converted AC wave form, and lastly the Inverter section that reconverts the original AC wave form into the desired frequency of an AC wave form. This is the heart of a drive.

The basic function of the drive hardware and software is to replicate an AC wave form, as accurately as possible, to the desired AC wave form need by the control system. The method used to create the new AC wave form is pulse width modulation (PWM). The inverter section of the drive pulses a voltage of different lengths of time to form a synthetic wave form of the desired frequency.

DRIVE CONTROL

One differentiator between manufacturers of drives is the software algorithm used to control the pulsing that creates the synthetic AC wave form, which ultimately controls the motor. There are two basic types of algorithms used for inverter control: volts per hertz control and sensorless vector control.

Volts per hertz control, also known as scalar control, uses a ratio of output voltage to output frequency for control of the width of the pulses of the inverter. For example, a 480 VAC motor controlled from a frequency 20hz to a frequency 60hz. This is a ratio of 480VAC ÷ 40hz = 12 volts per hertz.

As the volts per hertz example above shows, the control is a linear ratio. Figure 4 shows the volts per hertz ratio and the torque curve for a variable torque load. Note the torque curve is not linear where the volts per hertz curve, which controls the drive output, is linear. Therefore, the control of the motor torque is not as exact as sensorless vector control.

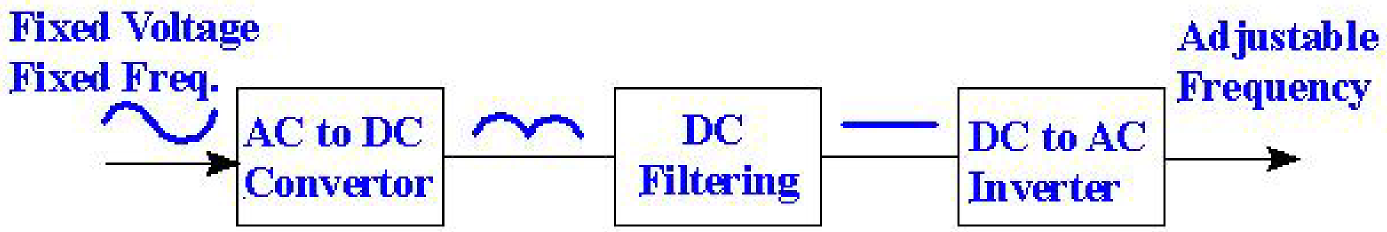

FIGURE 3 - Typical Variable Frequency Drive Hardware Configuration

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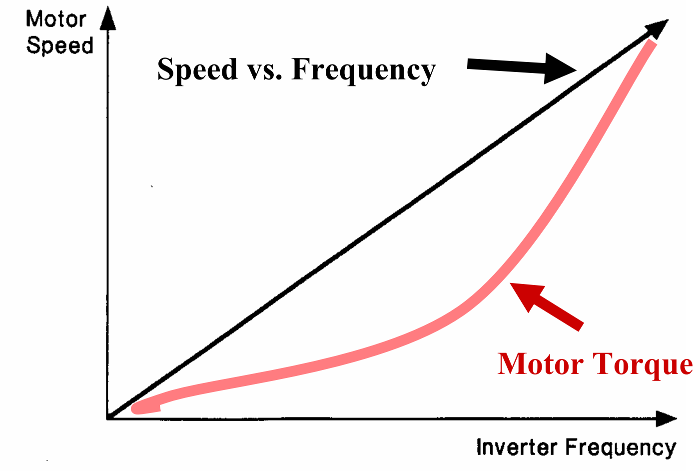

FIGURE 4 - Variable Torque Load Compared to Volts per Hertz Control

Advantages of volts per hertz control are:

- ✓ Simple, No Frills - Easy to Tune
- ✓ Ability to Control Several Motors From a Single Drive

Sensorless vector control is a software algorithm also used to control the pulsing of the inverter. The software models the motor stator magnetizing current and motor torque to determine the pulsing width of the drive inverter section. Although the algorithm does not use any actual feedback from the motor (meaning open loop control), the control is far more precise control than volts per hertz control. Further, the control more closely matches the actual torque curve of a variable torque load rather than the linear curve used by the volts per hertz algorithm.

Advantages of sensorless vector control are:

- ✓ More Precise than Volts per Hertz Control
- ✓ Maximizes and Controls Motor Torque
- ✓ Small Increase in Cost as no Additional Hardware is Needed

One note, sensorless vector control only allows one drive to control one motor.

CLEAN POWER DRIVES

The more switching transistors in the drive provide more pulses, making the shape of the synthetic sine wave more exact. The paths of conduction, or "pulses", a drive uses determine the exactness of the shape of the sine wave. 6 pulse drives are considered standard while 18 pulse drives are known as "clean power" because the sine wave is precise enough to contain few harmonics. However, 18 pulse drives are far more expensive than 6 pulse drives and generally are applied to motors above 200 horsepower.

Figure 5 is an example of a 6-pulse wave form. Note the hard edges and inexact sine wave form. This causes harmonics primarily concentrated around the 5th and 7th harmonic. The magnitude of the harmonics decrease farther away from the 5th and 7th harmonic frequencies.

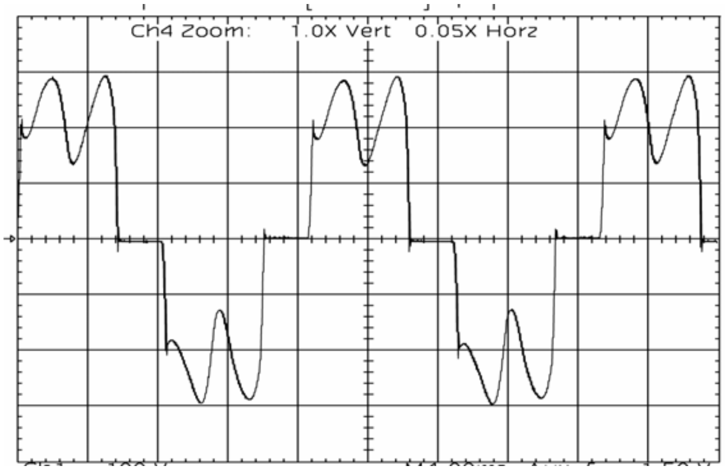

FIGURE 5 - 6 Pulse Voltage Wave Form

Figure 6 on the following page, show 18-pulse drive voltage and current wave forms. Note how much smoother the wave forms are when compared to the 6-pulse drive. Again, the largest concentration of harmonics are on both sides of the number of pulses - in the case of the 18-pulse drive, the 17th and 19th harmonics are the highest concentration. Further, the magnitude of the 17th and 19th harmonic disturbances of an 18-pulse are lower than the magnitude of 5th and 7th harmonics of 6-pulse drives.

The governing standard of acceptable harmonic content of an electrical system is IEEE Standard 519. It is noted that compliance with this standard is measured at the ***point of common coupling*** (PCC)- not at the drive it self. The PCC is the point in the electrical distribution system where the utility service connects to the facility distribution system.

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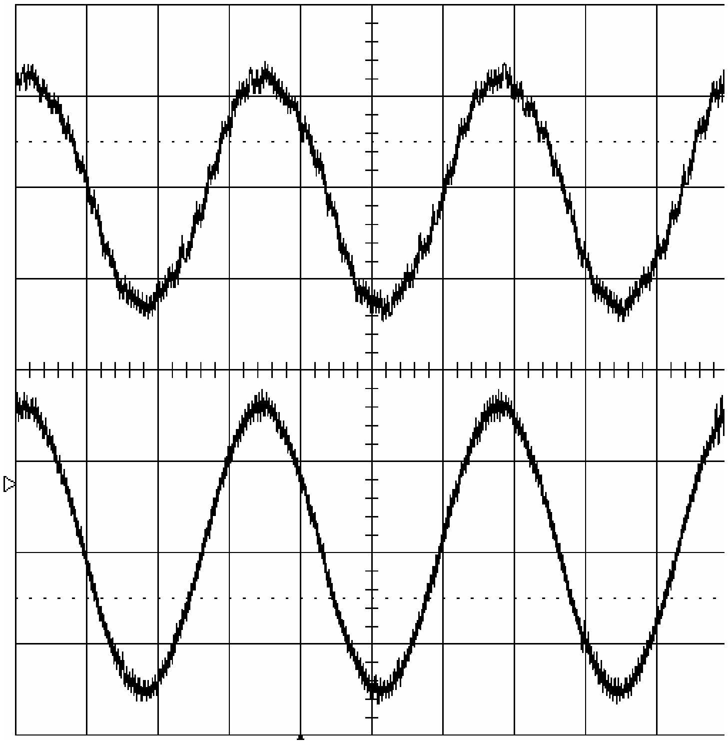

**FIGURE 6 - 18 Pulse Voltage Wave (Top)
18 Pulse Current Wave (Bottom)**

BYPASS

Often, variable frequency drives are specified with a bypass. A bypass is a series of contactors that allows starting of a motor across the line at full voltage. Why is this desired? In critical applications should the drive fail or need repair, the drive can be removed and the motor operated.

Figure 7 below is a three contactor bypass arrangement. In normal operation, contactors C-1 and C-3 are closed while contactor C-2 is open. The electrical power flows through the drive to motor.

In the bypass mode, contactors C-1 and C-3 are open while contactor C-2 is closed. Contactor C-2 is an across the line starter with motor protection.

A two contactor bypass is less costly option. In this arrangement, the C-3 contactor of Figure 7 is eliminated. The disadvantage is the line side power must be disconnected for removal of the drive. Therefore the motor cannot operate during this removal.

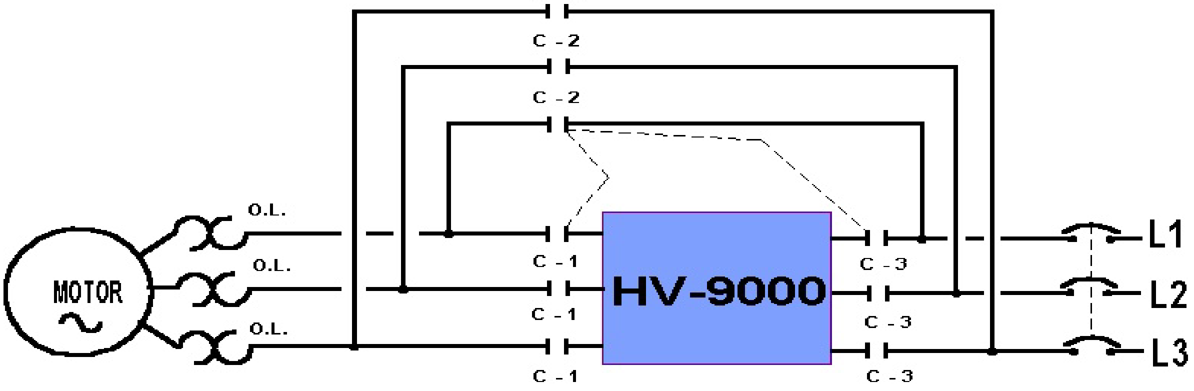

FIGURE 7 - Three Contactor Bypass